



1918

**TALLINNA TEHNIKAÜLIKOOL**  
TALLINN UNIVERSITY OF TECHNOLOGY

Department of Electrical Engineering

---

# **ADVANCED COURSE OF ELECTRICAL DRIVES**

## **Laboratory works**

Valery Vodovozov and Anton Rassõlkin

Tallinn

2013

Valery Vodovozov, Anton Rassõlkin. Advanced Course of Electrical Drives. Laboratory works  
Tallinn University of Technology  
Department of Electrical Engineering  
Tallinn, 2013

Tallinn University of Technology  
Department of Electrical Engineering  
Ehitajate tee 5, Tallinn 19086  
Telefon 620 3700  
Fax 620 3701

Copyright: Valery Vodovozov, Anton Rassõlkin, Tallinn University of Technology  
Department of Electrical Engineering, 2013

ISBN 978-9949-23-428-8

# TABLE OF CONTENTS

<b>INTRODUCTION</b> .....	<b>4</b>
<b>SAFETY WARNINGS</b> .....	<b>4</b>
<b>LABORATORY SETUP</b> .....	<b>4</b>
<b>JOB INSTRUCTIONS</b> .....	<b>6</b>
<b>WORK 1. COMMISSIONING OF THE DRIVES</b> .....	<b>6</b>
1.1 <i>Remote control from the cabinet console</i> .....	7
1.2 <i>Local control from the control panels</i> .....	7
1.3 <i>Data observation from the control panel</i> .....	8
1.4 <i>Reporting</i> .....	9
<b>WORK 2. MECHANICAL AND POWER CHARACTERISTICS</b> .....	<b>9</b>
2.1 <i>Taking the scalar control characteristics at nominal speed</i> .....	9
2.2 <i>Taking characteristics at different speeds and controls</i> .....	10
2.3 <i>Reporting</i> .....	10
<b>WORK 3. LOCAL CONTROL USING DRIVEWINDOW</b> .....	<b>10</b>
3.1 <i>Acquaintance with DriveWindow</i> .....	11
3.2 <i>Drive control</i> .....	12
3.3 <i>Drive monitoring and tracing</i> .....	12
3.4 <i>Saving and analysing of results</i> .....	13
3.5 <i>Reporting</i> .....	13
<b>WORK 4. ADAPTIVE PROGRAMMING</b> .....	<b>13</b>
4.1 <i>Programming the rectangle pulse</i> .....	15
4.2 <i>Testing the program</i> .....	16
4.3 <i>Programming and testing the ramping pulse</i> .....	17
4.4 <i>Reporting</i> .....	18
<b>WORK 5. TUNING THE DRIVE</b> .....	<b>18</b>
5.1 <i>Autotuning</i> .....	19
5.2 <i>Manual tuning</i> .....	20
5.3 <i>Reporting</i> .....	20
<b>WORK 6. DRIVING AN ELECTRIC VEHICLE</b> .....	<b>20</b>
6.1 <i>Pedal control of a vehicle drive</i> .....	21
6.2 <i>Program control of a vehicle drive</i> .....	21
6.3 <i>Reporting</i> .....	22
<b>REFERENCES</b> .....	<b>22</b>
<b>ANNEXES</b> .....	<b>23</b>
Annex 1. <i>Power Circuit of the Laboratory Setup</i> .....	23
Annex 2. <i>Control Circuits of the Laboratory Setup</i> .....	24
Annex 3. <i>Signals and Parameters</i> .....	25
Annex 4. <i>Functional Blocks for Adaptive Programming</i> .....	27
Annex 5. <i>Adaptive Program of ECE-15 (Urban Driving Cycle)</i> .....	30

## INTRODUCTION

These regulations are intended for use as a tutorial aid for laboratory works in AAV0040 *Advanced Course of Electrical Drives*. A student is expected to have acquired knowledge of the basic course of electrical drives, electrical motors, electronic components, standard electrical wiring, and electrical schematic symbols. He should read and understand the safety warnings prior to start working on the laboratory setup.

## SAFETY WARNINGS

1. Always remember the laboratory setup is a dangerous device. Never apply the mains power and never run the motors if it may cause danger or an injury.
2. Before powering the laboratory setup, make sure all equipment and measuring instruments are suitable for operation throughout the permissible speed, voltage, and current ranges.
3. Never switch on the mains without the instructor's permission.
4. In the case of overheating, smelling, the sparkles or electric arc between contacts, switch off the power source immediately by the STOP button of the remote panel, emergency push-button and the main switch on the cabinet console, or the red safety push-button on the laboratory switchboard.
5. Remember that the *STOP* key on the control panel has no effect if the control location is not set to *LOCAL*.
6. To avoid electric shock, never open the covers and do not touch the cables or the motors while the mains power is applied or the shafts rotate.
7. Do not run the motors over the nominal speed continuously and do not allow their long-term overloading.
8. Do not control the motors by direct device connecting/disconnecting; instead, use the keys of the control panel or the console buttons.
9. Do not exceed 5 power-ups in 10 minutes to exclude the installation damage.

## LABORATORY SETUP

The layout of the laboratory setup is presented in Fig. 1. The setup incorporates two electrical drives, namely, the testing drive the ABB ACS 800 and the loading drive ABB ACS 611. Every drive consists of a squirrel cage induction motor, AC/DC converter (3-phase bridge front-end rectifier) and a DC/AC converter (3-phase bridge IGBT motor-side inverter) coupled via an intermediate dc link. The shafts of the motors mounted on the single base are mechanically coupled through a cardan transmission to provide their joint rotation. The testing drive is furnished with an IGBT rectifier and a speed pedal to imitate the driver's habits in the case of the vehicle application. This power reversible system operates in the speed control mode to follow the studied test cycles. The loading drive built on a diode rectifier performs in the torque control mode to follow the torque references for studying multiple loads changing in a broad range. Electrical equipment is installed within a cabling cabinet the front panel of which is occupied by the remote control buttons, control panels, sockets, and measurement devices.

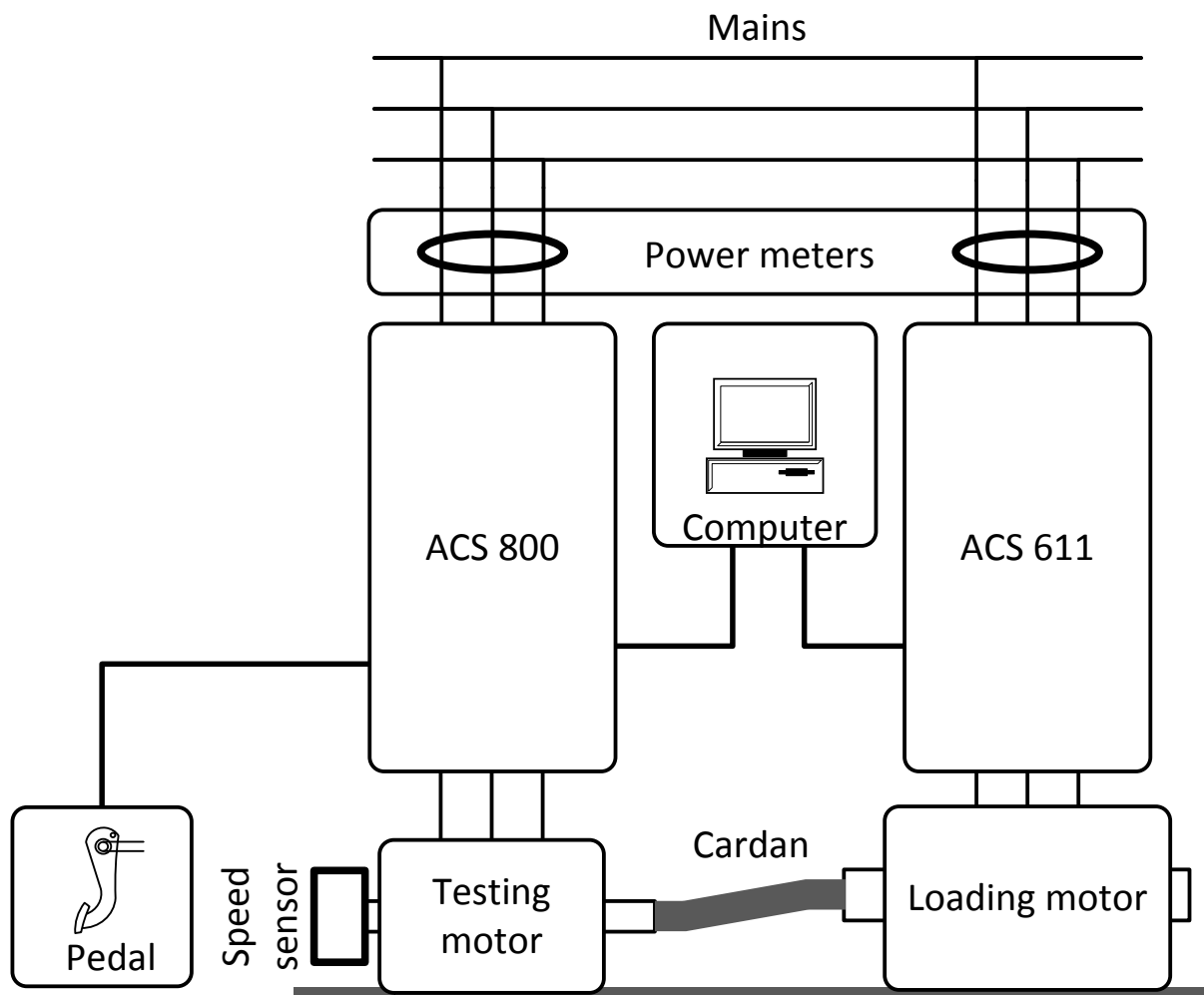


Fig. 1 Layout of the laboratory setup

The testing drive can operate in one of the three following control modes:

- remote (external) control from the console coupled through the input/output connections (I/O) or the fieldbus interface;
- local control from the control panel;
- program control from the computer software *DriveWindow* equipped with the model-based tool for online parameter tracing.

The loading drive during laboratory works operates only in local control mode from the control panel.

The principle of the testing drive operation depends on the loading drive as described in [1]. During the motoring, the rectifier feeds the dc link with an ac voltage, which, in turn, supplies the inverter running the motor. Instead, during the braking, the inverter feeds energy back from the motor to the supply lines or to the braking circuit through the dc link. The IGBT gating employs the space vector modulation providing the scalar control (constant voltage-frequency ratio) or the direct torque control (DTC) [2].

An electrical circuit of the laboratory setup power supply is presented in Annex 1. The control circuit is shown in Annex 2. Both electric drives are the 3-phase systems with input voltage of 380...500 V, output voltage of 0...415 V, input frequency of 48...63 Hz, and output frequency of 8...300 Hz. The

ACS 800-01-0025-3 maximal current is 62 A and output power is 22 kW. The ACS 611-0025-5 continuous current is 34 A at output power of 18,5 kW.

## JOB INSTRUCTIONS

### Work 1. Commissioning of the Drives

The work aims to learn how to start, to stop, to change the rotation direction, to control the drive from the remote console and the local panel, and to observe and measure the signals.

All these goals can be achieved throughout commissioning that is a system start-up providing testing and adjusting to assure proper functioning and understanding the principle of the drive operation.

The laboratory setup is mounted within the cabinet, the console of which is presented in Fig. 2. The cabinet has the sockets to attach the motors and to connect the measurement devices, the speed encoder, the speed pedal, and optical wires. To power on and power off the laboratory setup, the main switch is used. For extreme shutdown, the emergency push-pull button is intended. To run and stop the drives, the buttons are available. The drive control panels provide the local control. The power meters Merlin Gerlin Power Logic PM500 acquire full information about the input signals of each drive, such as voltages, currents, active, reactive and apparent powers, power factors, and total harmonic distortion. For speed measurements, the Leine & Linde 861007455 encoder of 9...30 VDC supply and 2048 pulses per revolution is fitted on the motor shaft with a display on the console.

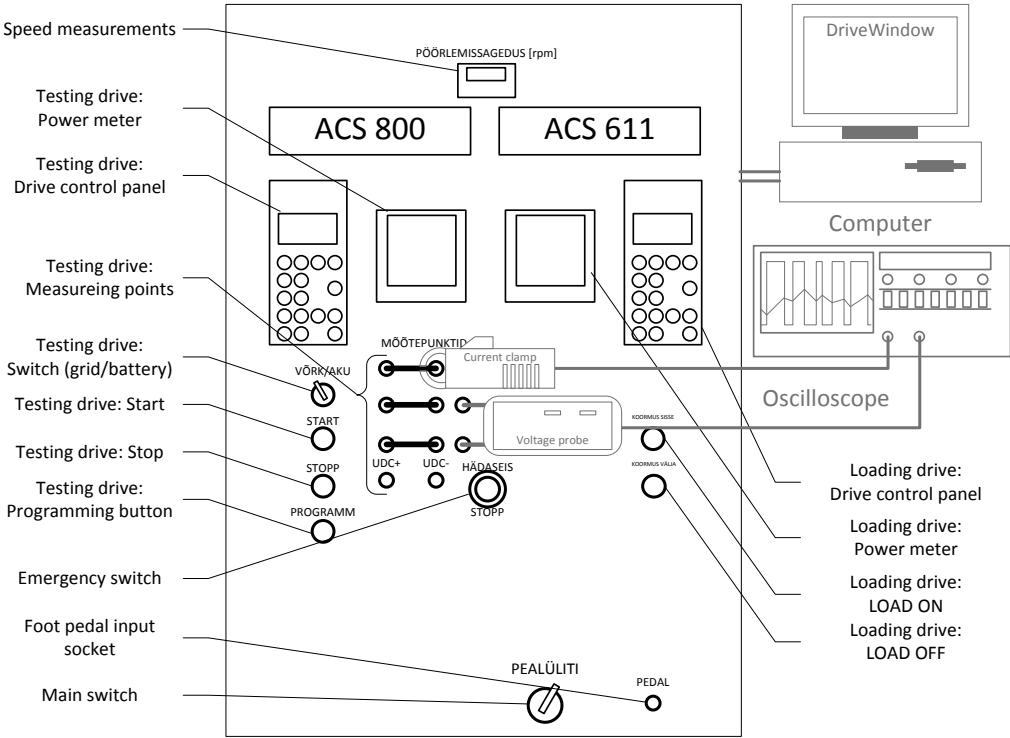
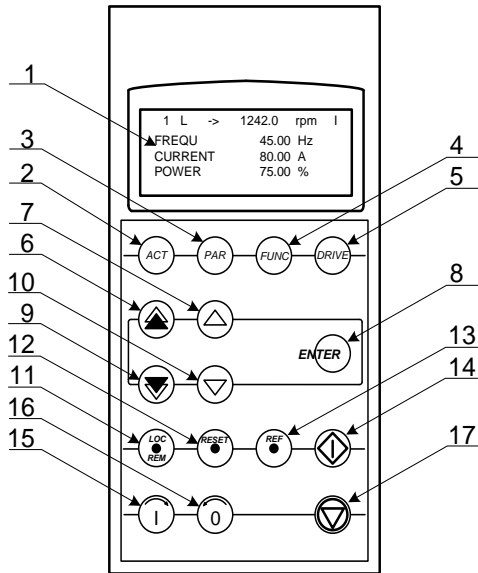


Fig. 2 Front panel of the cabinet

## 1.1 Remote control from the cabinet console

1. Familiarise with the laboratory setup. Find the main switch, the emergency push-button, the control equipment, the measurement devices, and the local control panels.
2. Power on the laboratory setup with the main switch. On the local control panel of the testing drive shown in Fig. 3, press the *ACT* key and explore the status row displayed in Table 1. If **\*\*FAULT\*\*** or **\*\*WARNING\*\*** appear, press the *RESET* key.



#	Name	Function
1	LCD	Display, 4 lines
2	ACT	Actual Signals Mode
3	PAR	Parameter Mode
4	FUNC	Function Mode
5	DRIVE	Drive Selection Mode
6	PAGEUP	Large step up
7	UP	Small step up
8	ENTER	Set the choice
9	PAGEDN	Large step down
10	DOWN	Small step down
11	LOC/REM	Local/Remote control
12	RESET	Fault reset
13	REF	Reference setting
14	START	Run the motor
15	FORWARD	Forward direction
16	REVERSE	Reverse direction
17	STOP	Stop the motor

Fig. 3 Local control panel

Table 1.

Module ID	Control status	Direction	Reference	Drive status
1 – motor-side	L – LOCAL	→ forward	Hz	1 – running
2 – line-side	empty or R– REMOTE	← reverse	V	0 – stopped
				empty – disabled

3. Ensure the testing drive is in the REMOTE control mode (no *L* visible in the control status); otherwise, press the *LOC/REM* key to replace LOCAL by REMOTE.
4. To run the testing drive remotely, press its *START* button on the console. Press and release the speed pedal for speed adjustment. Check the drive status to ensure the drive is running.
5. To stop the testing drive, press its *STOP* button.

## 1.2 Local control from the control panels








1. Ensure the motors do not rotate.
2. Read and record the following data from the testing and loading motor nameplates: motor manufacturer, type, isolation class, IP, voltage, wiring scheme, frequency, speed, power, current, power factor, and weight.
3. Learn about the following general procedure of the parameter setting of the control panel:

- to enter a *Parameter Mode*, press the *PAR* key;
  - to scroll parameter groups, press the *PAGEUP* and *PAGEDN* keys;
  - to scroll parameters within a group, use the *UP* and *DOWN* keys;
  - to activate the setting of a new value, press the *ENTER* key;
  - change the parameter value by the *UP* and *DOWN* keys or fast change by the *PAGEUP* and *PAGEDN* keys;
  - to fix your choice, press the *ENTER* key.
4. Apply the above given procedure to the testing drive. Enter *START-UP DATA* (parameter group 99), set the *FACTORY APPLICATION MACRO* and the *SCALAR MOTOR CONTROL MODE*, and enter the testing motor data found from the motor nameplate: *MOTOR NOMINAL VOLTAGE, CURRENT, FREQUENCY, SPEED, POWER*.
  5. Apply the same procedure to the loading drive, but the *DTC MOTOR CONTROL MODE*, and enter the loading motor data.
  6. Proceed from the *REMOTE* to *LOCAL* control mode by pressing the *LOC/REM* key (*L* must be visible on the display).
  7. Set the frequency *Reference* of the testing drive. To this aim, press the *REF* key, then press the *UP/DOWN* to slow reference change or the *PGUP/PGDOWN* keys to fast change. Press the *ENTER* key to save the new reference in the memory until the power switch-off or further changing.
  8. To run the motor, press the *START* key on the control panel. To stop the motor press the *STOP* key. To change the direction of the shaft rotation, press the *REVERSE* or *FORWARD* key, then *START* and *STOP* again.

### 1.3 Data observation from the control panel

1. Run the testing drive in the *LOCAL* control mode to the small reference value.

2. Press the *ACT* key  to enter the *Actual Signals Mode* (parameter group 01).

- To select a row (a blinking cursor indicates the selected row).  
- To enter the actual signal selection function. **ENTER**
- To select an actual signal.  
- To change the actual signal group.  
- To accept the selection and to return to the Actual Signal Display Mode. **ENTER**
- To cancel the selection and keep the original selection. 

3. Read and record gradually the data listed in Table 2 of the motor-side inverter. To change a signal, move the blinking cursor by the *UP/DOWN* keys and press the *ENTER* key in the selected row, then select an actual signal by the *UP/DOWN* keys and press the *ENTER* key again. Find the list of other signals and parameters with their address codes and short descriptions in Annex 3.



Table 2.

Parameter	Name	Description
01.02	<i>SPEED</i>	Motor speed, rpm
01.03	<i>FREQUENC[Y]</i>	Inverter output frequency, Hz
01.04	<i>CU[RRENT]</i>	Motor current, A
01.05	<i>TORQUE</i>	Motor torque, % of nominal
01.06	<i>POWER</i>	Motor power, % of nominal
01.07	<i>DC VOLTA[GE]</i>	Intermediate link voltage, VDC
01.08	<i>MAINS VO[LTA]GE]</i>	Supply rms voltage, V

4. Stop the drive and power off the laboratory setup.

## 1.4 Reporting

1. Layout and specification of the laboratory setup.
2. Drive and motor data, including the motor manufacturer, type, isolation class, IP, voltage, wiring scheme, frequency, speed, power, current, power factor, and weight.
3. Given reference value of the testing drive.
4. Table of the actual signals.
5. Conclusions regarding the estimation, comparison, and explanation of the results obtained.

## Work 2. Mechanical and Power Characteristics

*The work aims to study the drive operation in statics by taking, exploring, and explaining the mechanical and power characteristics at both the SCALAR and the DTC controls.*

The mechanical characteristics describe the speed-torque ratios on the shaft of the testing motor. To measure the testing motor power, torque, and speed, the control panel is used.

The power characteristics describe the power-torque, efficiency-torque, and efficiency-speed ratios of the testing drive. The drive efficiency is calculated as the ratio of the testing motor power found from the control panel and the consumed power estimated by the power meter of the testing drive.

### 2.1 Taking the scalar control characteristics at nominal speed

1. Power on the laboratory setup.
2. In the LOCAL control mode, set the SCALAR control of the testing drive and the DTC control of the loading drive using parameter 99.04.
3. Assign the nominal reference frequency of the testing drive using the *REF* key of the control panel. Assign the reference torque of the loading drive to zero by the *REF* key of the loading drive control panel.
4. Run the testing drive by the *START* key on the control panel.
5. To run the loading drive, press the LOAD ON button on the console and the *START* key on the control pane.

6. Estimate the consumed power from the power meter of the testing drive. Estimate the motor power, torque, and speed from the control panel of the testing drive.
7. Recalculate the power and torque values to W and Nm, respectively. Calculate the drive efficiency. Write down the estimated and calculated values into the protocol table.
8. Increase gradually the loading torque from zero to 100 %. Periodically, at 5 different torque values, write down the same values as in items 6 and 7. Then, return to the no-load performance.
9. Draw the speed-torque, power-torque, and efficiency-torque characteristics.

## 2.2 Taking characteristics at different speeds and controls

1. Increase the reference frequency of the testing drive above the nominal frequency (between 50 and 70 Hz) and repeat items 6 to 9 of the previous section. Ensure that minimum frequency parameter 20.07 is set at least to value -70Hz and maximum frequency parameter 20.08 is set at least to value 70Hz.
2. Decrease the reference frequency of the testing drive below the nominal value (between 50 and 20 Hz) and repeat again items 6 to 9 of the previous section.
3. Stop the drives by the *STOP* keys and the press the LOAD OFF button.
4. Take the DTC control of the testing drive. Repeat items 3 to 9 of the previous section and items 1 and 3 of the current section at the DTC control.
5. Restore the SCALAR control and power off the laboratory setup.

## 2.3 Reporting

1. The table of all the experiments each row of which includes the measured consumed and motor powers (%) and speed (rpm), and calculated consumed and motor powers (W), torque (Nm), and efficiency at the given frequency (Hz) and torque (%).
2. The set of the SCALAR speed-torque traces taken at the nominal, high, and low frequencies.
3. The set of the DTC speed-torque traces taken at the nominal, high, and low frequencies.
4. The set of the SCALAR power-torque traces taken at the nominal, high, and low frequencies.
5. The set of the DTC power-torque traces taken at the nominal, high, and low frequencies.
6. The SCALAR efficiency-torque traces taken at the nominal, high, and low frequencies.
7. The DTC efficiency-torque traces taken at the nominal, high, and low frequencies.
8. The set of the SCALAR efficiency-speed traces taken at different torques.
9. The set of the DTC efficiency-speed traces taken at different torques.
10. Conclusion concerning the estimation, comparison, and explanation of the results obtained.

## Work 3. Local Control using *DriveWindow*

*The work aims to employ the drive control using the DriveWindow toolbox and to learn about its signal monitoring, parameterisation, tracing, data saving, and analysing.*

*DriveWindow* is a Windows application for commissioning and maintaining ABB drives of ACS 600, ACS 800, ACS 6000, and DCS 600 models [3]. To apply the toolbox, the drives are connected to the

computer through a set of fibre optical wires though only one of them can be controlled at once. The *DriveWindow* employs the following functions: control operations (start, stop, references, etc.), signal monitoring, parameterisation, data and fault logging, data backing-up and restoring, and networking.

The user interface shown in Fig. 4 handles the standard *Windows* areas using the keyboard and mouse editing, moving, dragging, and resizing possibilities. It includes the following controls:

1. Title bar
2. Menu bar
3. Toolbars
4. Status bar
5. Window area
6. Within the windows, scrollbars are shown, if scrolling is possible

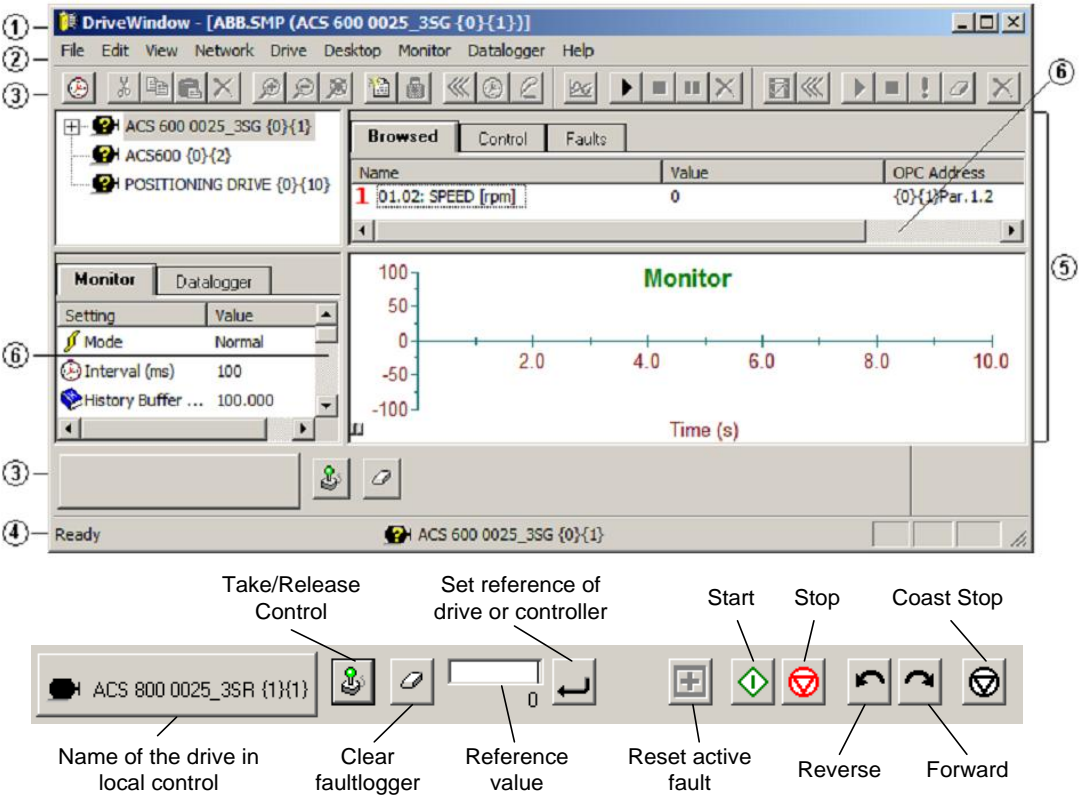


Fig. 4 User interface of *DriveWindow* and toolbar explanation

The toolbars and the status bar can individually be hidden by a user. The output *DriveWindow* data can be presented and saved in graphical and numerical forms for the further analysis.

### 3.1 Acquaintance with *DriveWindow*

1. Power on the testing drive.
2. Using the control panel, set the the *DriveWindow* program as the control tool (no *L* visible in the control status).

3. Switch on the computer and run *DriveWindow*.
4. To link *DriveWindow* to the testing drive, choose *ABB SMP* string in the *Select OPC Server* dialog box.
5. Find the main controls of the user interface: title bar, menu bar, toolbars including the *Standard* toolbar, the *Monitor* toolbar, the *Logger* toolbar, and the *Drive* panel at the bottom, status bar along the bottom line, and window area divided by four panels: *Browse tree* and *Item sets* on a top as well as *Trend settings* and *Trend display* below.

### 3.2 Drive control

1. Select the *TESTING DRIVE* in the *Browse tree* panel.
2. Take the control by toggling the *Take/Release Control* button.
3. Examine the status, name, and address of the currently controlled drive.
4. Reset the fault and clear the fault logger if an error occurs.
5. Assign the given reference frequency (30...70 Hz) into the edit field and click the *Set Reference* button or press *Enter* to initiate the drive.
6. Run the drive, and then stop it.
7. Change the motor direction of rotation and run it again.
8. Employ the coast stop.
9. Release the control and ensure the drive is adjustable from the control panel.

### 3.3 Drive monitoring and tracing

1. Take the control.
2. To learn about the drive acceleration, choose *Parameters* in the *Browse tree* panel and assign parameter 22.02 with a given value (5...15 s) in the *Item sets* panel.
3. In the *Trend Settings* panel, set *X-Axis Length* above the given acceleration time. Increase the *History Buffer time* to at least 200 s to keep the full range of the tracking values
4. To add the motor voltage, frequency, torque, and speed for monitoring, choose *01 ACTUAL SIGNALS* in the *Browse tree* panel and drag the required strings to the *Trend Settings* panel. The numeric images appear in front of the added items. The *Delete* button permits removing unnecessary items from monitoring.
5. To start monitoring, click the *Start or Continue Monitoring* button in the *Monitor* toolbar and right away run the drive. The traces appear on the screen.
6. Wait until the running process completes and click the *Stop Monitoring* button. Then stop the drive also.
7. To scale the trace swing, use *Adapt Y-Axis* from the *Axis* submenu or *Autoscale* from the *Scaling* submenu of the *Monitor* menu.
8. In the course of stopped or paused monitoring, click the drawing area to display the graph cursor measuring the traces.

### 3.4 Saving and analysing of results

1. To process the data, select *Export* in the *Graph* submenu and assign a name of the created *.txt* file. Later, open the file by *Microsoft Excel*, recalculate per-unit data into Volts, Amperes, or Hertz, and build the required charts.
2. To save the traces for further proceeding, select *Save As* command and name and comment the new *.dwt* file. The saved graphs contain just enough information for restoring. In the future, by double clicking or selecting *Open* command in the *Graph* submenu, the saved file may be restored.
3. To use the traces in other applications, first copy them into the clipboard using *Copy Graph* command in *Edit* menu and then paste to the target document.
4. To print the traces when the current printer is unavailable, use the *Microsoft Office Document Image Writer*.
5. After successful saving, clear the monitor by the *Clear* button and return parameter 22.02 to 3 s.
6. To finalise the work, power off the computer and the laboratory setup.

### 3.5 Reporting

1. Scaled timing traces of speed, voltage, current, and frequency.
2. Voltage-frequency chart built using the voltage and frequency data.
3. Speed-torque chart built using the speed and torque data.
4. Conclusions regarding the estimation, comparison, and explanation of results obtained.

## Work 4. Adaptive Programming

*The work aims to learn about adaptive programming and to employ such simple driving cycles as a rectangle pulse and a ramping pulse.*

Conventionally, users can control the drive operation using different parameters. Each parameter has a fixed set of choices or a setting range. Parameterisation provides enough fussy control, but the number of choices is limited thus restricting user's control possibilities. Adaptive programming enlarges the control range without an application of any special programming language [4], [5]. Instead, *DriveWindow* plays the role of the programming tool here. A user builds the program linking the function blocks called Block Parameter Sets shown in Annex 4. These blocks are also used for reading values from the drive application programs and for transferring data to the drive application programs. Each function block includes five parameters.

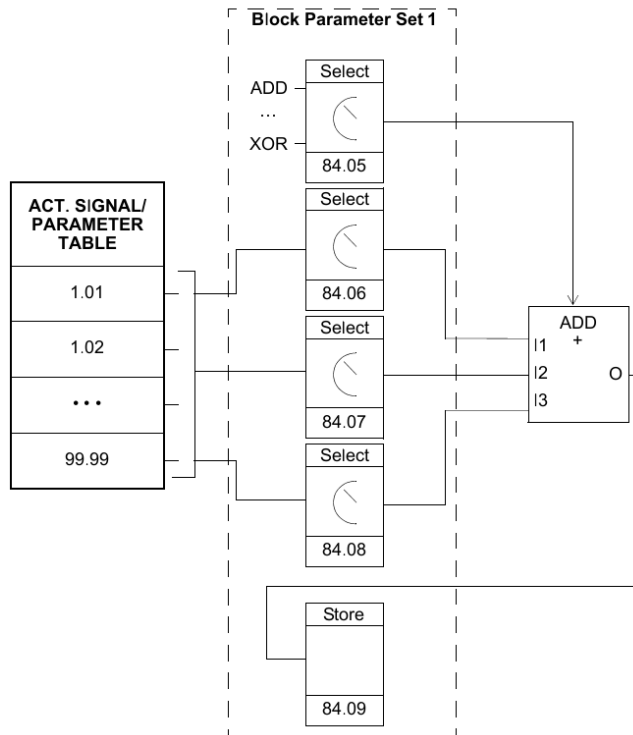


Fig. 5 Block Parameter Set 1

Fig. 5 shows an example of the Block Parameter Set 1 as the ACS800 Standard Application Program (parameters 84.05 to 84.09):

- 84.05 sets the function block type
- 84.06 sets the source that input I1 of the function block is connected to
- 84.07 sets the source that input I2 of the function block is connected to
- 84.08 sets the source that input I3 of the function block is connected to

The read-only parameter 84.09 stores the value of the function block output. The user can document the program by drawing the block diagram template sheets. An adaptive program may consist of up to 15 function blocks.

To link the output of an adaptive program to the drive, two parameters are used, namely, a connection parameter and a source selection parameter (pointer). Fig. 6 shows how to use the value stored in parameter 84.09 as a speed reference REF1 for the ACS800 Standard Application Program.

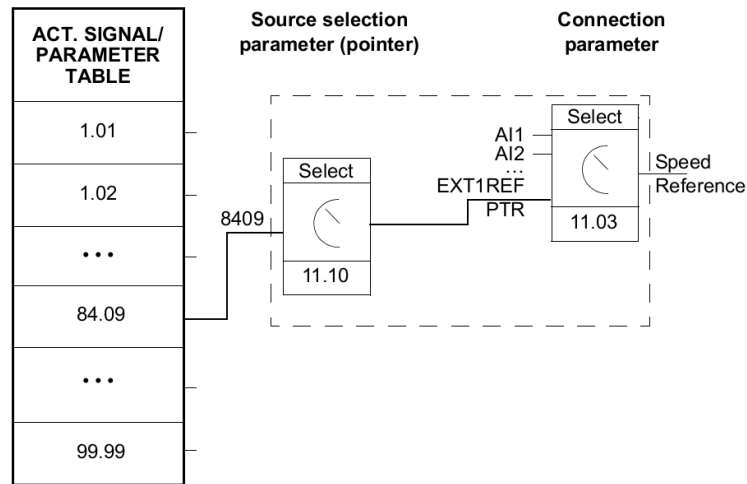


Fig. 6 Example of adaptive programming

#### 4.1 Programming the rectangle pulse

1. Power on the laboratory setup and set the testing drive to the REMOTE control mode
2. Switch on the computer, run *DriveWindow*, and link it to the testing drive.
3. To begin adaptive programming, choose the operation mode EDIT using parameter 83.01.
4. Prepare the program shown in Fig. 7 for the rectangle pulse shown in Fig. 8. To this aim, choose the function block TOFF as the Block Parameter Set 1 (84.05). For the input I1 of the Block Parameter Set 1 (84.06), assign the console PROGRAM button as the source (digital input DI6, address +.001.017.05). For the input I2 of the Block Parameter Set 1 (84.07), assign the 24-bit integer as the timer value  $T_{stop}$  in the range of C.15000...C.20000 (15...20 s, one bit corresponds to 1 ms).

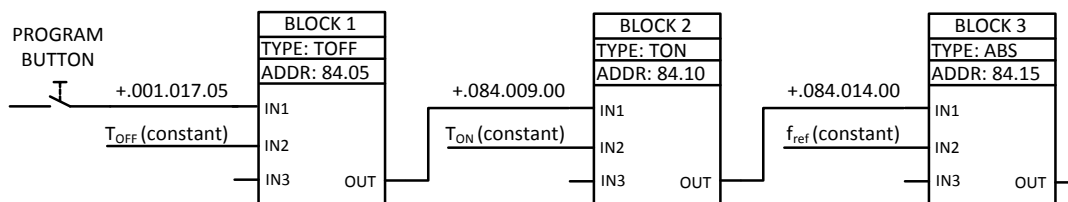


Fig. 7 Adaptive program of a rectangle pulse

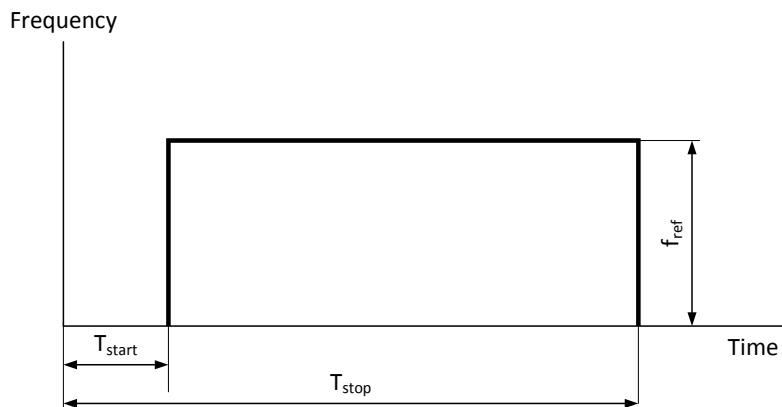


Fig. 8 Rectangle pulse of reference frequency

5. Choose the function block TON as the Block Parameter Set 2 (84.10). For input I1 of the Block Parameter Set 2 (84.11), assign the output of the Block Parameter Set 1 as the source (address +.084.009.00). For the input I2 of the Block Parameter Set 2 (84.12), assign the 24-bit integer as the timer value  $T_{start}$  in the range of C.5000...C.10000 (5...10 s, one bit corresponds to 1 ms).
6. Choose the function block ABS as the Block Parameter Set 3 (84.15). For the input I1 of the Block Parameter Set 3 (84.16), assign the output of the Block Parameter Set 2 as the source (address +.084.014.00). For the input I2 of the Block Parameter Set 3 (84.17), assign the Constant 1 (85.01) as the source (address +.085.001.00).
7. Set the Constant 1 for the adaptive program (85.01) in the range of 8000...20000 (20...50 Hz, 400 bits corresponds to 1 Hz).
8. Draw the developed program using Fig. 7 as an example.

## 4.2 Testing the program

1. Set the acceleration/deceleration parameters 22.02 and 22.03 to zero.
2. To test the developed program, choose the operation mode RUN for the adaptive program using parameter 83.01.
3. Set the external reference REF1 (11.03) to the signal source (PARAM 11.10). Assign the source address +.084.019.00 for parameter 11.10.
4. Assign the signals for the testing drive monitoring: the speed (01.02), frequency (01.03) and digital input status (01.17). Increase the *History Buffer* to at least 200 s to keep the full range of the tracking values and set *X-Axis Length* to at least 250 s.
5. Run the testing drive by the START button and the adaptive program by the PROGRAM button on the console.
6. Observe the monitoring traces. Estimate the difference between the tracing frequency and the desired rectangle pulse. Select the proper scale factor for the external reference to match the speed and frequency scales.
7. Stop monitoring and save the traces.
8. Stop the testing drive using the STOP button on the console.



### 4.3 Programming and testing the ramping pulse

1. To enhance the above program, choose the operation mode EDIT for the parameter 83.01.
2. Convert the rectangle pulse of Fig. 8 to the ramping pulse shown in Fig. 9. To this aim, choose the function block RAMP as the Block Parameter Set 4 (84.20). For the input I1 of the Block Parameter Set 4 (84.21), assign the output of the Block Parameter Set 3 as the source (address +.084.019.00). For the input I2 of the Block Parameter Set 4 (84.22), assign the value in the range of C.2000...C.4000 step/sec as the step to the positive direction. For the input I3 of the Block Parameter Set 4 (84.23), assign the value in the range of C.500...C.1500 step/sec as the step to the negative direction.

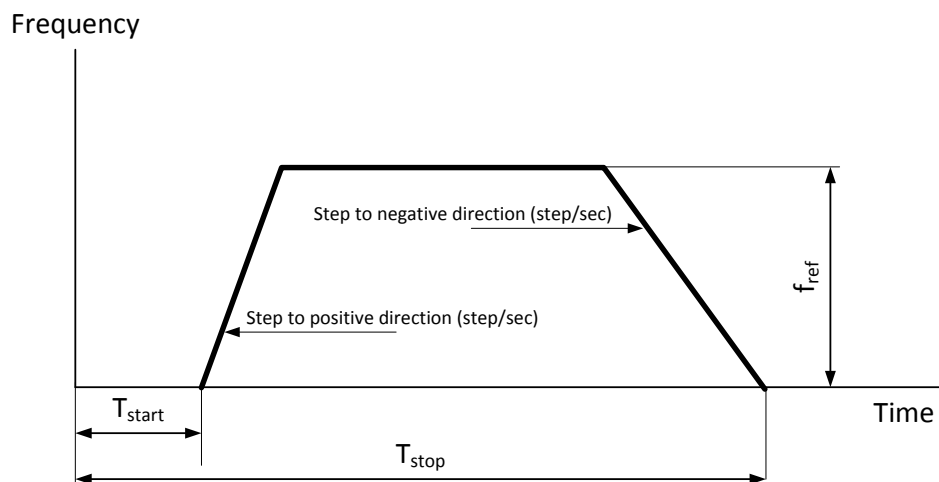


Fig. 9 Pulse with ramps

3. To test the prepared program, choose the operation mode RUN (83.01).
4. Set the external reference REF1 (11.03) to the signal source (PARAM 11.10). Assign the source address +.084.024.00 for parameter 11.10.
5. Assign the signals for the testing drive monitoring: the speed (01.02), frequency (01.03) and digital input status (01.17).
6. Run the testing drive by the START button and the adaptive program by the PROGRAM button on the console.
7. Observe the monitoring traces. Estimate the difference between the tracing frequency and the desired ramping pulse.
8. Draw the developed program using Fig. 7 as an example and save the traces.
9. Stop the testing drive.
10. Restore the signal source AI1 for external reference REF1 (11.03). Set the STOP operation for the adaptive program (83.01).
11. Switch off the computer and power off the laboratory setup.

## 4.4 Reporting

1. Two adaptive programs for the given values of the starting time ( $T_{start}$ ), stopping time ( $T_{stop}$ ), frequency ( $f_{ref}$ ), and ramp steps.
2. Speed and frequency timing diagrams taken with *DriveWindow*.
3. Conclusion concerning the estimation, comparison and explanation of the results

## Work 5. Tuning the Drive

The work aims to learn about the drive settings, to understand the components of the PID controller, and to employ autotuning and manual tuning.

The block diagram of the PID speed controller is shown in Fig. 10. It is composed of the P regulator of the system gain (23.01), the I regulator of the integral control component (23.02), the D regulator of the derivative control component (23.03), and the prediction loop for compensation the derivative acceleration (23.04). To protect the drive from damage, all the PID controller parameters are restricted. Thus, exceeding the gain maximum limit causes the speed oscillation. An integration time defines the rate at which the controller responds the stable error. The shorter the integration time, the faster the continuous error value is corrected. Too short integration time makes the control unstable. Derivation will make the control more responsive for disturbances by boosting the controller output if the error value changes. The longer the derivation time, the more the speed controller output is boosted upon the error change. If the derivation time is set to zero, the controller will perform as a PI controller, otherwise, as a PID controller.

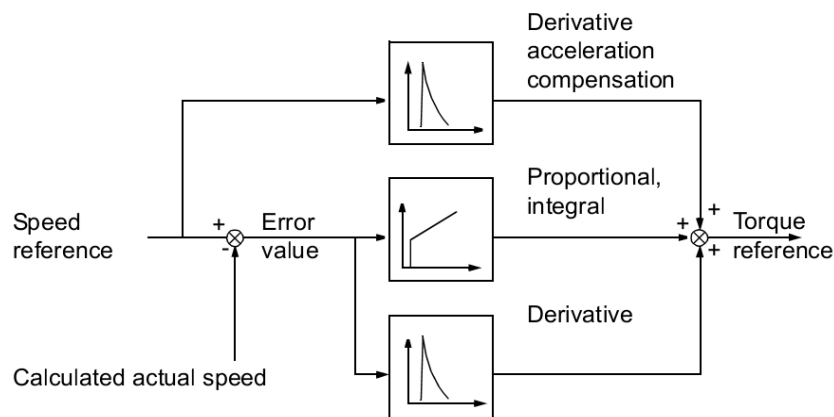


Fig. 10 Simplified block diagram of the speed controller

At the DTC control, this controller can be tuned automatically. To this aim, the Autotune Run is executed which estimates the motor and the loading machine common inertia and assigns the required PID components. As an alternative, the system provides a possibility to tune the speed controller manually changing a gain of the P regulator, an integration time of the I regulator, and a derivation time of the D regulator. Fig. 11 shows the speed responses on the speed step reference (typically, 1 to 20 %) upon different settings of the speed controller

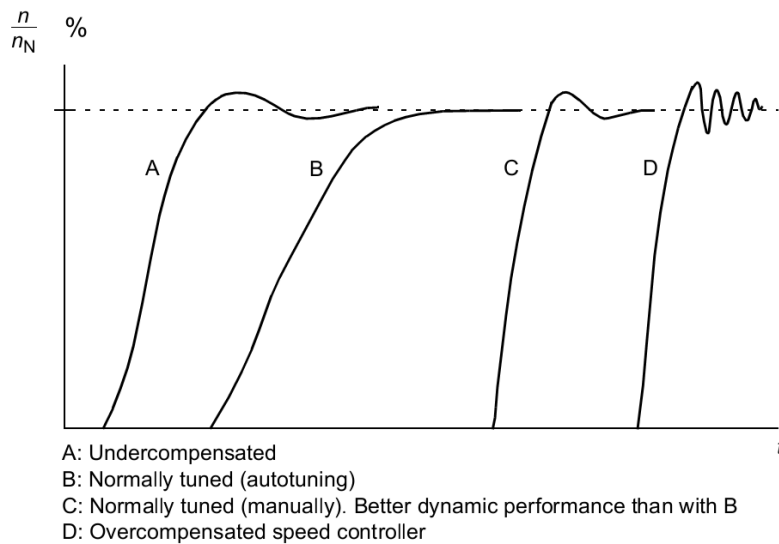


Fig. 11 Speed responses upon the step speed reference

## 5.1 Autotuning

1. Power on the laboratory setup and set the testing drive to the REMOTE control mode
2. Switch on the computer, run *DriveWindow*, and link it to the testing drive.
3. Take the DTC control of the testing drive using parameter 99.04.
4. Run the testing drive at 20...40% of the nominal motor speed.
5. To execute autotuning, set parameter 23.06 to YES. Then, stop the drive.
6. Refresh the window area, read the parameters of the speed controller resulted from autotuning, and fill them in Table 3.

Table 3.

Test number	23.01 GAIN	23.02 INTEGRATION TIME	23.03 DERIVATION TIME	Running time, ms	Overrun, %	Steady-state error, %

7. Prepare the rectangle pulse shown in Fig. 8 above using the directions and parameters of Work 4.
8. Assign the signals for the testing drive the monitoring: the reference frequency from the output of adaptive program (84.19) with a scaling factor of 0,0025, the actual frequency resulted from autotuning (01.03), and the digital input status (01.17) for fixing the cycle starting point. Increase the *History Buffer* to at least 200 s to keep the full range of the tracking values and set *X-Axis Length* to at least 250 s.
9. Run the testing drive and the adaptive program.

10. Estimate the running time, the overrun portion, and the steady-state error, and add these data to Table 3.
11. Save the speed responses and stop the testing drive.

## 5.2 Manual tuning

1. Assign 23.02 to the maximum integration time of 1000 ms and set 23.04 to zero.
2. Increase gradually the gain from 1 to 50. Periodically, at 4 different gain values, run the testing drive from the adaptive program, monitor the reference and the actual frequencies, estimate the running time, the overrun portion, and the steady-state error, fill them in Table 3, and save the speed responses. Then, restore the gain value obtained from autotuning.
3. Decrease gradually the integration time from 1 to 0,01 s. Periodically, at 4 different integration time values, run the drive from the adaptive program, monitor the reference and the actual frequencies, estimate the running time, the overrun portion, and the steady-state error, fill them in Table 3, and save the speed responses. Then, restore the integration time value obtained from autotuning.
4. Increase gradually the derivation time from zero to 30 ms. Periodically, at 4 different gain values, run the drive from the adaptive program, monitor the reference and the actual frequencies, estimate the running time, the overrun portion, and the steady-state error, fill them in Table 3, and save the speed responses. Then, restore the derivation time value obtained from autotuning and stop the drive.
5. Restore the signal source AI1 for external reference REF1 (11.03). Set the STOP operation for the adaptive program (83.01). Restore the SCALAR control of the testing drive (99.04).
6. Switch off the computer and power off the laboratory setup.

## 5.3 Reporting

1. Speed response of the autotuned drive.
2. Speed responses of the drive with the manually tuned P regulator.
3. Speed responses of the drive with the manually tuned I regulator.
4. Speed responses of the drive with the manually tuned D regulator.
5. Conclusions regarding the estimation, comparison, and explanation of results obtained.

## Work 6. Driving an Electric Vehicle

*The work aims to learn about the Urban Driving Cycle, to become familiar with the corresponding adaptive program, and to understand the load influence on the drive settings.*

The Urban Driving Cycle, also known as ECE R15 cycle, is shown in Fig. 12. It has been designed to represent typical driving conditions of busy European cities for supporting the low car motor loading. When the drive runs, the vehicle pauses for 11 s, then accelerates slowly to 15 km/h in 4 s, cruises at the constant speed for 8 s, brakes to a full stop in 5 s, and then stays immovable for 21 s. At 49 s, the vehicle accelerates slowly to 32 km/h in 12 s, cruises for 24 s, brakes slowly to a full stop in 11 s, and

then pauses for 21 s again. At 117 s, the car accelerates to 50 km/h in 26 s, cruises for 12 s, decelerates to 35 km/h in 8 s, cruises for 13 s, brakes to a full stop in 12 s, and then pauses for 7 s. An adaptive program given in Annex 5 serves as a useful tool for building the Urban Driving Cycle.

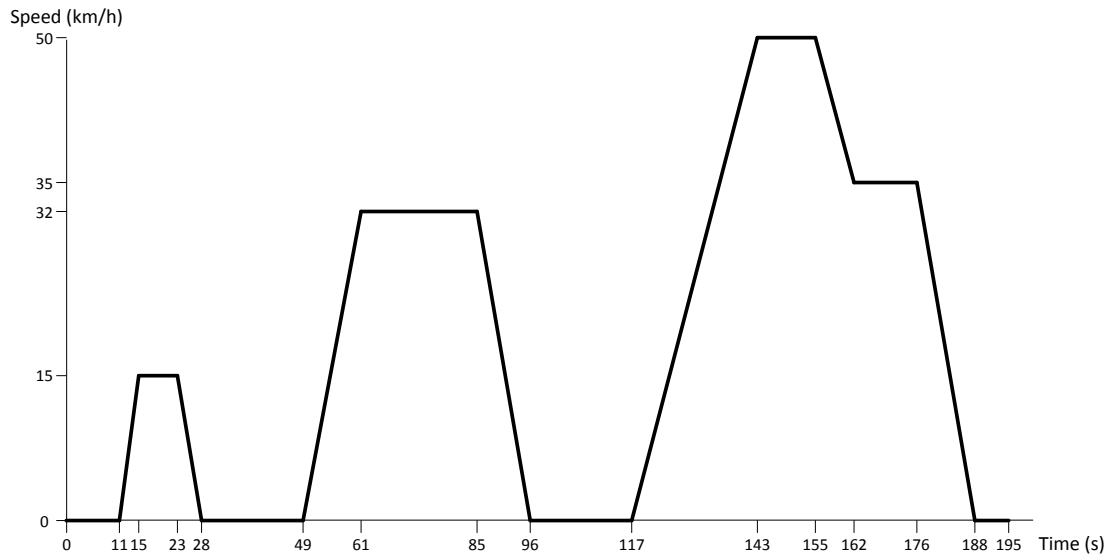


Fig. 12 ECE-15 (Urban Driving Cycle)

## 6.1 Pedal control of a vehicle drive

1. Power on the laboratory setup and set the testing drive to the REMOTE control mode
2. Switch on the computer, run *DriveWindow* and link it to the testing drive.
3. Take the SCALAR control of the testing drive and the DTC control for the loading drive.
4. Assign the speed (01.02) for monitoring. Increase the *History Buffer* to at least 200 s to keep the full range of the tracking values and set *X-Axis Length* to at least 250 s.
5. Using the speed pedal, try to reproduce the ECE-15 Cycle shown in Fig.12. To this aim, run the testing drive, monitor it, and save the traces. Then stop the drive.

## 6.2 Program control of a vehicle drive

1. Replace the pedal control by the program control under the ECE-15 Urban Driving Cycle. To this aim, set 99.02 to USER1 LOAD macro.
2. Assign the following signals for monitoring: speed (01.02), frequency (01.03), torque (01.05), power (01.06), and digital input status (01.17).
3. Run the testing drive and the adaptive program, employ monitoring, and save the traces.
4. Turn on the loading drive.
5. Increase gradually the loading torque from zero to 100 %. Periodically, at 4 different torque values, monitor the same values. Save the traces at each torque. Then, return to the no-load performance.

6. Stop both the loading and the testing drives.
7. Restore the FACTORY macro (99.02).
8. Switch off the computer and power off the laboratory setup.

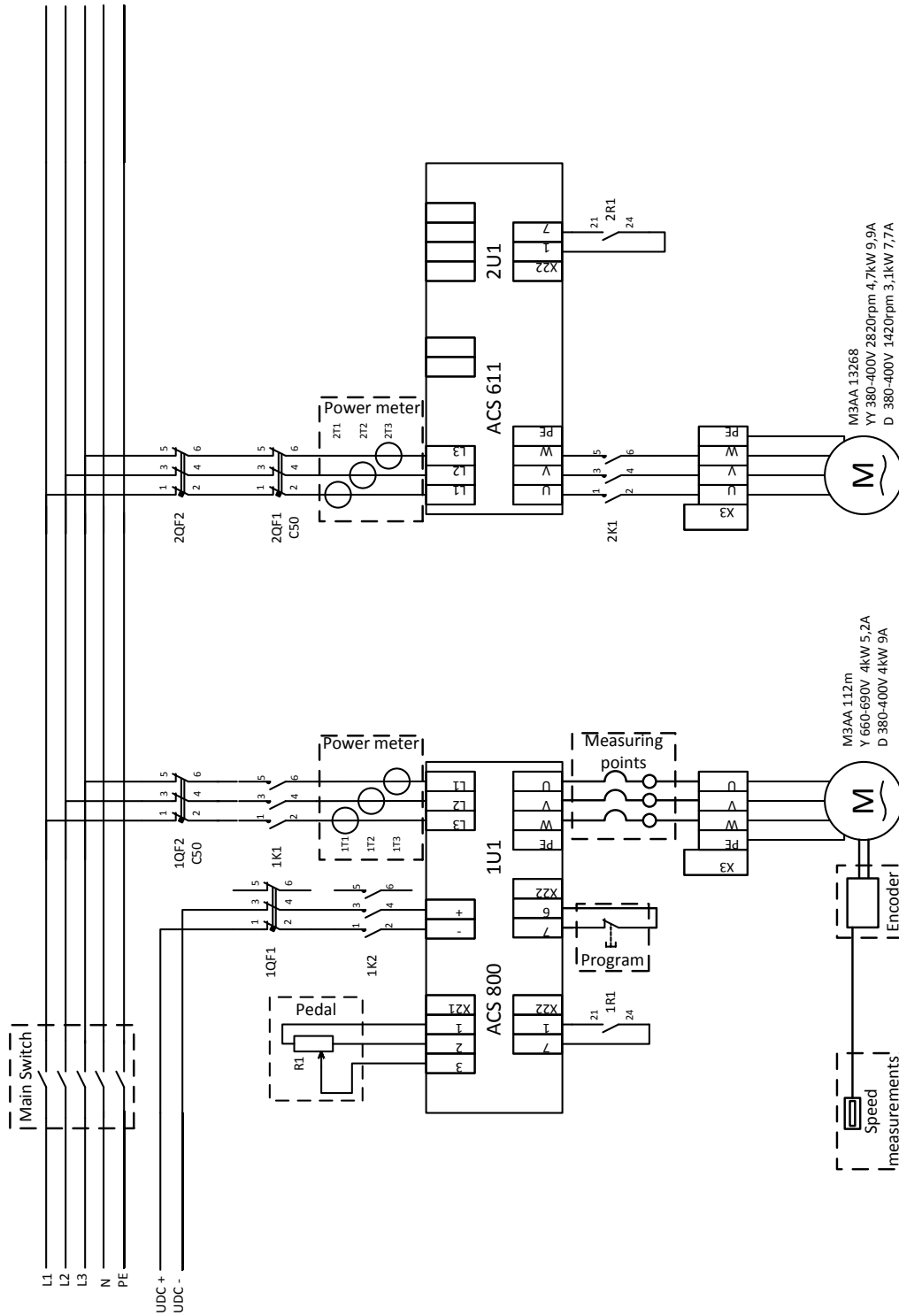
### **6.3 Reporting**

1. The speed timing diagram of the ECE-15 drive cycle estimated under the pedal control.
2. The speed, frequency, torque, and power timing diagrams of the ECE-15 drive cycle taken under the program control.
3. Conclusions regarding the estimation, comparison, and explanation of results obtained.

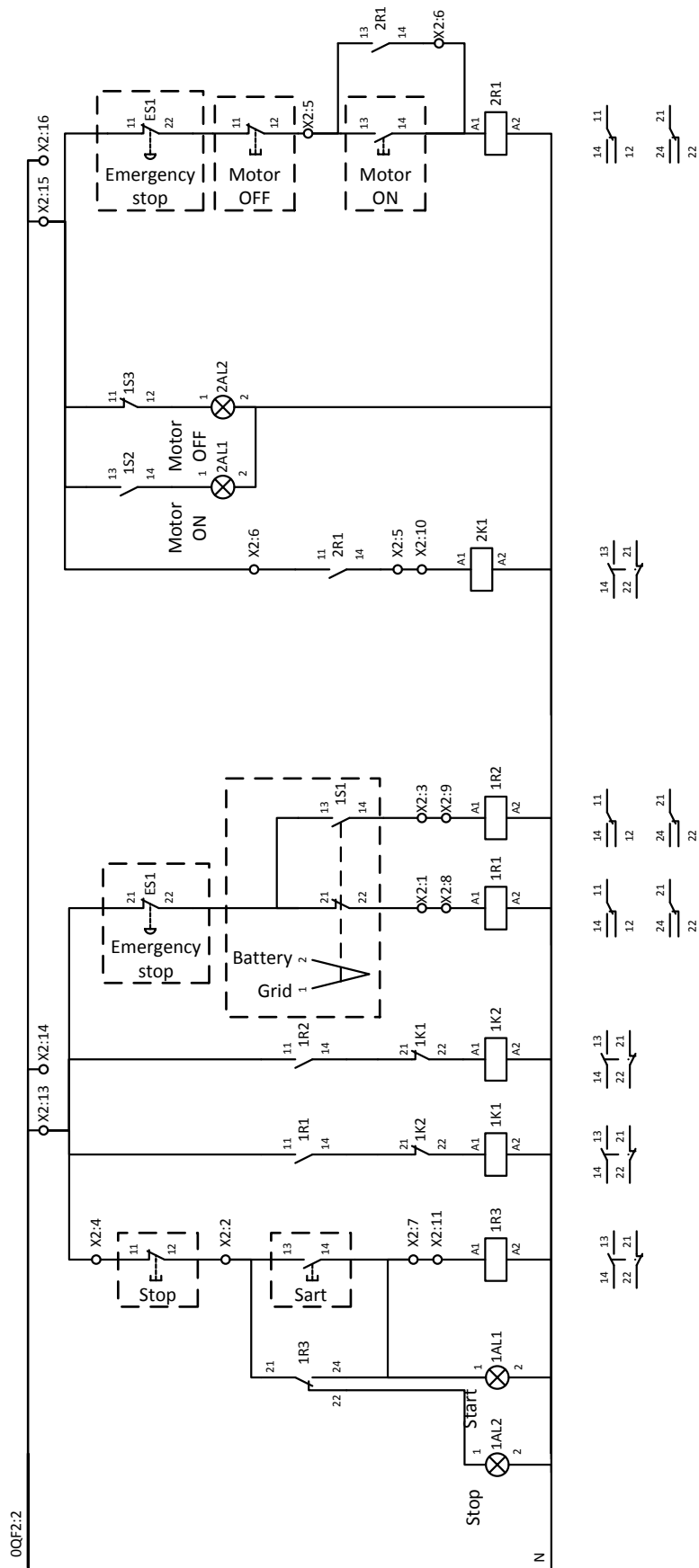
## **REFERENCES**

1. V. Vodovozov and D. Vinnikov, *Electronic Systems of Motor Drive*, Tallinn: TTU, 2008, 248 p.
2. *ACS800-31 Drives Hardware Manual*, ABB Inc, 2005, 132 p.
3. *DriveWindow2 Software Manual*, ABB Inc, 2006, 200 p.
4. *ACS800 Firmware Manual. Standard Application Program 7.x*, ABB Inc, 2005, 264 p.
5. Application Guide. Adaptive Program, ABB Inc, 2005, 42 p.

Annex 1. Power Circuit of the Laboratory Setup



## Annex 2. Control Circuits of the Laboratory Setup



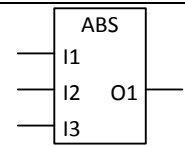
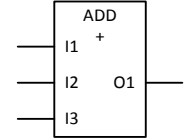
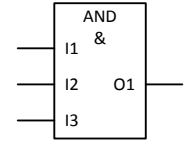
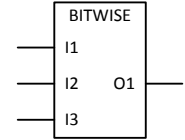
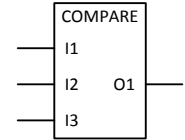
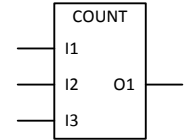
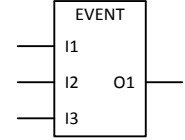
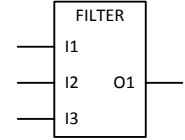
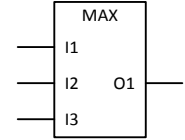
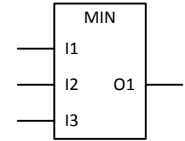


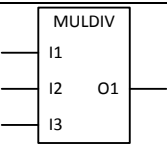
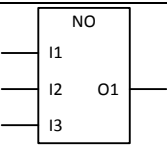
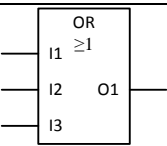
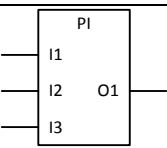
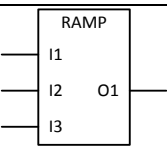
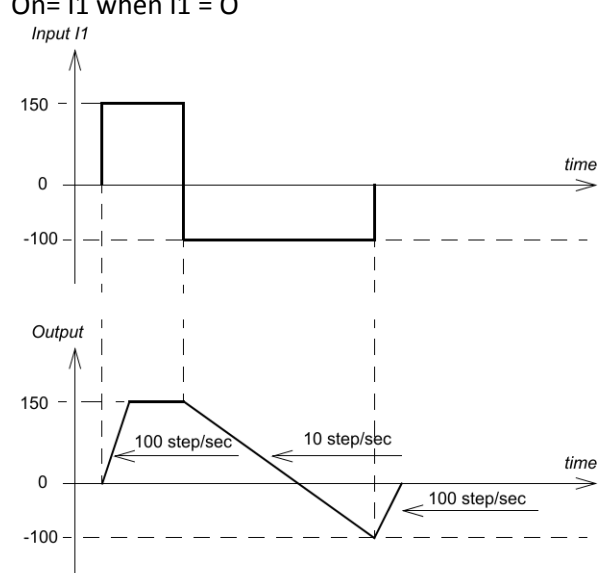
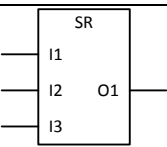
### Annex 3. Signals and Parameters

Par.	Name	Description
01	ACTUAL SIGNALS	Basic signals for monitoring of the drive
01.02	SPEED	Calculated motor speed in rpm.
01.03	FREQUENCY	Calculated inverter output frequency.
01.04	CURRENT	Measured motor current.
01.05	TORQUE	Calculated motor torque.
01.06	POWER	Motor power. 100 is the nominal power.
01.07	DC BUS VOLTAGE	V Measured intermediate circuit voltage.
01.08	MAINS VOLTAGE	Calculated supply voltage.
01.09	OUTPUT VOLTAGE	Calculated motor voltage.
10	START/STOP/DIR	The sources for external start, stop and direction contro
10.01	EXT1 STRT/STP/DIR	Defines the connections and the source of the start, stop and direction commands for external control location 1 (EXT1).
	NOT SEL	No start, stop and direction command source.
	DI ( <i>n</i> )	Digital input, according to it number( <i>n</i> )
10.02	EXT2 STRT/STP/DIR	Defines the connections and the source of the start, stop and direction commands for external control location 2 (EXT2).
10.03	REF DIRECTION	Enables the control of rotation direction of the motor, or fixes the direction.
	FORWARD	Fixed to forward
	REVERSE	Fixed to reverse
	REQUEST	Direction of rotation control allowed
11	REFERENCE SELECT	Panel reference type, external control location selection and external reference sources and limits
11.01	KEYPAD REF SEL	Selects the type of the reference given from panel.
	REF1 (rpm)	Speed reference in rpm. (Frequency reference (Hz) if parameter 99.04 is SCALAR.)
	REF2 (%)	%-reference. The use of REF2 varies depending on the application macro. For example, if the Torque Control macro is selected, REF2 is the torque reference.
11.03	EXT REF1 SELECT	Selects the signal source for external reference REF1
	AI ( <i>n</i> )	Analogue input, according to it number( <i>n</i> )
	PARAM 11.10	Source selected by parameter 11.10
11.10	EXT 1 REF PTR	Defines the source or constant for value PAR 11.10 of parameter 11.03
20	LIMITS	Drive operation limits.
20.01	MINIMUM SPEED	Defines the allowed minimum speed.
20.02	MAXIMUM SPEED	Defines the allowed maximum speed.
20.03	MAXIMUM CURRENT	Defines the allowed maximum motor current.
20.05	OVERVOLTAGE CTRL	Activates or deactivates the overvoltage control of the intermediate DC link.
20.06	UNDERVOLTAGE CTRL	Activates or deactivates the undervoltage control of the intermediate DC link.
20.07	MINIMUM FREQ	Defines the minimum limit for the drive output frequency.
23	SPEED CTRL	Speed controller variables. The parameters are not visible if parameter 99.04=SCALAR.
23.01	GAIN	Defines a relative gain for the speed controller.
		0.0 ... 250.0 Gain

Par.	Name	Description
23.02	INTEGRATION TIME	Defines an integration time for the speed controller 0.01 ... 999.97 s Integration time
23.03	DERIVATION TIME	Defines the derivation time for the speed controller. 0.0 ... 9999.8 ms Derivation time value.
23.04	ACC COMPENSATION	Defines the derivation time for acceleration/(deceleration) compensation.
23.05	SLIP GAIN	Defines the slip gain for the motor slip compensation control.
23.06	AUTOTUNE RUN	Start automatic tuning of the speed controller.
83	ADAPT PROG CTRL	Control of the Adaptive Program execution.
83.01	ADAPT PROG CMD	Selects the operation mode for the Adaptive Program.
	STOP	Stop. The program cannot be edited.
	RUN	Run. The program cannot be edited.
	EDIT	Stop to edit mode. Program can be edited.
84	ADAPTIVE PROGRAM	selections of the function blocks and their input connections
84.01	STATUS	Shows the value of the Adaptive Program status word.
84.05	BLOCK1	Selects the function block for Block Parameter Set 1.
84.06	INPUT1	Selects the source for input I1 of Block Parameter Set 1.
84.07	INPUT2	Selects the source for input I2 of Block Parameter Set 1.
84.08	INPUT3	Selects the source for input I3 of Block Parameter Set 1.
84.09	OUTPUT	Stores and displays the output of Block Parameter Set 1.
..	...	...
84.79	OUTPUT	Stores the output of Block Parameter Set 15.
85	USER CONSTANTS	Storage of the Adaptive Program constants and messages.
85.01	CONSTANT1	Sets a constant for the Adaptive Program.
...	...	...
85.10	CONSTANT10	Sets a constant for the Adaptive Program.
99	START-UP DATA	Language selection. Definition of motor set-up data.
99.01	LANGUAGE	Selects the display language.
99.02	APPLICATION MACRO	Selects the application macro.
99.04	MOTOR CTRL MODE	Selects the motor control mode.
99.05	MOTOR NOM VOLTAGE	Defines the nominal motor voltage.
99.06	MOTOR NOM CURRENT	Defines the nominal motor current.
99.07	MOTOR NOM FREQ	Defines the nominal motor frequency.
99.08	MOTOR NOM SPEED	Defines the nominal motor speed.
99.09	MOTOR NOM POWER	Defines the nominal motor power.

## Annex 4. Functional Blocks for Adaptive Programming

Name	Illustration	Type	Operation
ABS		Arithmetic function	The output is the absolute value of input I1 multiplied by I2 and divided by I3. $O = I1 \cdot I2 / I3$
ADD		Arithmetic function	The output is the sum of the inputs. $O = I1 + I2 + I3$
AND		Logical function	The output is true if all connected inputs are true.
BITWISE		Arithmetic function	The block compares bits of three 24 bit word inputs and forms the output bits as follows: $O = (I1 \text{ OR } I2) \text{ AND } I3$
COMPARE		Comparative function	Output bits 0, 1 and 2: - If $I1 > I2$ , $O = 001$ (Output bit 0 is set.) - If $I1 = I2$ , $O = 010$ (Output bit 1 is set.) - If $I1 < I2$ , $O = 100$ (Output bit 2 is set.)
COUNT		Counter function	The counter function counts rising edges of the input I1. The counter is reset by the rising edge of input I2 and limited to the value set with the input I3. I1: Trigger input I2: Reset I3: Max limit for the counter (B0..B19 -> 0..1048575) O: Value of the counter (B0..B19 -> 0..1048575), and status of the counter (B20). B20 = 1: Counter is at max limit or input I3 is negative.
EVENT		Event function	Input I1 triggers the event. I2 selects the parameter index from which the event message (text string) is read. I3 selects the type of the event (warning or fault).
FILTER		Filtering function	The output is the filtered value of input I1. Input I2 is the filtering time. $O = I1 \cdot (1 - e^{-t/I2})$
MAX		Comparative function	The output is the highest input value. $O = \text{MAX}(I1, I2, I3)$
MIN		Comparative function	The output is the lowest input value. $O = \text{MIN}(I1, I2, I3)$

Name	Illustration	Type	Operation
MULDIV		Arithmetic function	The output is the product of input I1 and input I2 divided by input I3. $O = (I1 \cdot I2) / I3$
NO			The block does not do anything
OR		Logical function	The output is true if any of the inputs is true.
PI		PI controller	The output is input I1 multiplied by I2-100 plus integrated I1 multiplied by I3-100. $O = I1 \cdot I2 - 100 + (I3 - 100) \cdot \int I1$
RAMP		Ramp function	The block uses input I1 as a reference value. The step values (inputs I2 and I3) increase or decrease the output O as long as the output differs from limit I1. When O = I1, the output remains steady. Input I1: Reference value Input I2: Step to positive direction (step-sec). Increase the output, when O < I1. Input I3: Step to negative direction (step-sec). Decrease the output, when O > I1. $O_n = O_{n-1} + I2$ when $I1 > O$ $O_n = O_{n-1} - I3$ when $I1 < O$ $O_n = I1$ when $I1 = O$
			
SR		Logical function	Set-reset block. Input I1 sets and I2 and I3 reset the output. - If I1, I2 and I3 are false, the current value remains at the output. - If I1 is true and I2 and I3 are false, the output is true.

Name	Illustration	Type	Operation
			- If I2 or I3 is true, the output is false
SWITCH-B		Logical function	The output is equal to input I2 if input I1 is true and equal to input I3 if input I1 is false.
SWITCH-I		Logical function	The output is equal to input I2 if input I1 is true and equal to input I3 if input I1 is false.
TOFF		Timing function	<p>The output is true when input I1 is true. The output is false when input I1 has been false for a time equal or longer than input I2.</p> <p>b</p>
TON		Timing function	<p>The output is true when input I1 has been true for a time equal or longer than input I2. The output is false when the input is false</p>
TRIGG		Timing function	<p>The rising edge of input I1 sets the output bit 0 for one program cycle.  The rising edge of input I2 sets the output bit 1 for one program cycle.  The rising edge of input I3 sets the output bit 2 for one program cycle.</p> <p><b>Example</b></p> <p><math>T_c =</math> Program cycle time</p>
XOR		Logical function	The output is true if one input is true, otherwise the output is false.

## Annex 5. Adaptive Program of ECE-15 (Urban Driving Cycle)

Name	Value	OPC Address
84.01: STATUS	1h	{0}{1}Par.84.1
84.02: FAULTED	+000.000.00	{0}{1}Par.84.2
84.05: BLOCK1	TOFF	{0}{1}Par.84.5
84.06: INPUT1	+001.017.05	{0}{1}Par.84.6
84.07: INPUT2	C. 26000	{0}{1}Par.84.7
84.08: INPUT3	+000.000.00	{0}{1}Par.84.8
84.09: OUTPUT	0	{0}{1}Par.84.9
84.10: BLOCK2	TON	{0}{1}Par.84.10
84.11: INPUT1	+084.009.00	{0}{1}Par.84.11
84.12: INPUT2	C. 11000	{0}{1}Par.84.12
84.13: INPUT3	+000.000.00	{0}{1}Par.84.13
84.14: OUTPUT	0	{0}{1}Par.84.14
84.15: BLOCK3	ABS	{0}{1}Par.84.15
84.16: INPUT1	+084.014.00	{0}{1}Par.84.16
84.17: INPUT2	C. 6000	{0}{1}Par.84.17
84.18: INPUT3	+000.000.00	{0}{1}Par.84.18
84.19: OUTPUT	0	{0}{1}Par.84.19
84.20: BLOCK4	TOFF	{0}{1}Par.84.20
84.21: INPUT1	+001.017.05	{0}{1}Par.84.21
84.22: INPUT2	+085.001.00	{0}{1}Par.84.22
84.23: INPUT3	+000.000.00	{0}{1}Par.84.23
84.24: OUTPUT	0	{0}{1}Par.84.24
84.25: BLOCK5	TON	{0}{1}Par.84.25
84.26: INPUT1	+084.024.00	{0}{1}Par.84.26
84.27: INPUT2	+085.002.00	{0}{1}Par.84.27
84.28: INPUT3	+000.000.00	{0}{1}Par.84.28
84.29: OUTPUT	0	{0}{1}Par.84.29
84.30: BLOCK6	ABS	{0}{1}Par.84.30
84.31: INPUT1	+084.029.00	{0}{1}Par.84.31
84.32: INPUT2	C. 12800	{0}{1}Par.84.32
84.33: INPUT3	+000.000.00	{0}{1}Par.84.33
84.34: OUTPUT	0	{0}{1}Par.84.34
84.35: BLOCK7	TOFF	{0}{1}Par.84.35
84.36: INPUT1	+001.017.05	{0}{1}Par.84.36
84.37: INPUT2	+085.003.00	{0}{1}Par.84.37
84.38: INPUT3	+000.000.00	{0}{1}Par.84.38
84.39: OUTPUT	0	{0}{1}Par.84.39
84.40: BLOCK8	TON	{0}{1}Par.84.40
84.41: INPUT1	+084.039.00	{0}{1}Par.84.41
84.42: INPUT2	+085.004.00	{0}{1}Par.84.42
84.43: INPUT3	+000.000.00	{0}{1}Par.84.43

Name	Value	OPC Address
84.44: OUTPUT	0	{0}{1}Par.84.44
84.45: BLOCK9	ABS	{0}{1}Par.84.45
84.46: INPUT1	+084.044.00	{0}{1}Par.84.46
84.47: INPUT2	C. 20000	{0}{1}Par.84.47
84.48: INPUT3	+000.000.00	{0}{1}Par.84.48
84.49: OUTPUT	0	{0}{1}Par.84.49
84.50: BLOCK10	TOFF	{0}{1}Par.84.50
84.51: INPUT1	+001.017.05	{0}{1}Par.84.51
84.52: INPUT2	+085.005.00	{0}{1}Par.84.52
84.53: INPUT3	+000.000.00	{0}{1}Par.84.53
84.54: OUTPUT	0	{0}{1}Par.84.54
84.55: BLOCK11	TON	{0}{1}Par.84.55
84.56: INPUT1	+084.054.00	{0}{1}Par.84.56
84.57: INPUT2	+085.003.00	{0}{1}Par.84.57
84.58: INPUT3	+000.000.00	{0}{1}Par.84.58
84.59: OUTPUT	0	{0}{1}Par.84.59
84.60: BLOCK12	ABS	{0}{1}Par.84.60
84.61: INPUT1	+084.059.00	{0}{1}Par.84.61
84.62: INPUT2	C. 14000	{0}{1}Par.84.62
84.63: INPUT3	+000.000.00	{0}{1}Par.84.63
84.64: OUTPUT	0	{0}{1}Par.84.64
84.65: BLOCK13	MAX	{0}{1}Par.84.65
84.66: INPUT1	+084.019.00	{0}{1}Par.84.66
84.67: INPUT2	+084.034.00	{0}{1}Par.84.67
84.68: INPUT3	+000.000.00	{0}{1}Par.84.68
84.69: OUTPUT	0	{0}{1}Par.84.69
84.70: BLOCK14	MAX	{0}{1}Par.84.70
84.71: INPUT1	+084.069.00	{0}{1}Par.84.71
84.72: INPUT2	+084.049.00	{0}{1}Par.84.72
84.73: INPUT3	+084.064.00	{0}{1}Par.84.73
84.74: OUTPUT	0	{0}{1}Par.84.74
84.75: BLOCK15	RAMP	{0}{1}Par.84.75
84.76: INPUT1	+084.074.00	{0}{1}Par.84.76
84.77: INPUT2	C. 1100	{0}{1}Par.84.77
84.78: INPUT3	C. 900	{0}{1}Par.84.78
84.79: OUTPUT	0	{0}{1}Par.84.79
85.01: CONSTANT1	85000	{0}{1}Par.85.1
85.02: CONSTANT2	49000	{0}{1}Par.85.2
85.03: CONSTANT3	145000	{0}{1}Par.85.3
85.04: CONSTANT4	117000	{0}{1}Par.85.4
85.05: CONSTANT5	166000	{0}{1}Par.85.5

